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Runoff and Sediment Rates on San Mateo and Querencia Soils, Rio Puerco Watershed Management Area, NM[1]

R. Aguilar and E. F. Aldon[2]

Precipitation input and runoff and sediment removal were measured on two different soils (Querencia loam and San Mateo sandy clay loam) within the Rio Puerco Watershed of northern New Mexico. Study objectives were to quantity runoff and sediment removal and define differences between the soils in hydrologic response to high intensity summer precipitation. Annual sediment removal was 10 to 15 times greater from the finer textured San Mateo soil than from the coarser Querencia soil. The sediment yield difference was attributed to differences in surface texture and subsoil structure that control infiltration, permeability, and runoff rates. Study results indicate that restorative management practices on southwestern rangelands should be directed toward those soil-vegetation communities that are more susceptible to runoff and sediment problems.

Keywords: Erosion, convective summer precipitation, soil texture and structure, infiltration, permeability

Introduction

The Rio Puerco Watershed Management Area (fig. 1) located in north-central New Mexico has been included among the highest sediment yielding drainage areas in the United States (Dortignac 1956). High sediment loads are a natural characteristic of the stream, as suggested by the Spanish name, implying "muddy river," assigned to the drainage by early explorers and colonizers. Yet a substantial reduction in total plant cover and density through heavy grazing, especially during the period 1880 to 1920 (Dortignac and Hickey 1963), has led to an exceptionally high rate of gully erosion. The principal objective of this study was to evaluate differences in runoff and sediment yield from San Mateo and Querencia soils and their associated plant communities. These two soil/vegetation assemblages occur extensively within the watershed.

[1]*This research was conducted in cooperation with the USDI Bureau of Land Management.*

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Study Area

The Rio Puerco Watershed area encompasses approximately 207,172 ha. Elevations range from 1,662 to 2,743 m above sea level. Mean annual precipitation ranges from 216 mm in the lower elevations to 322 mm at the

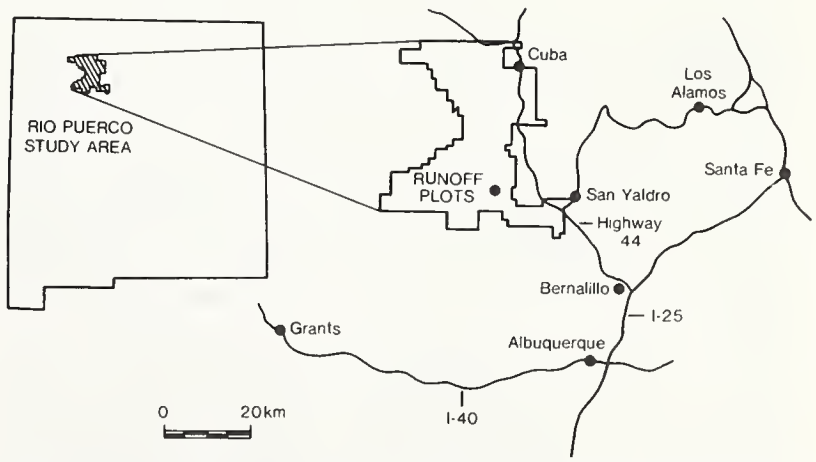

Figure 1.—Location of the runoff study plots within the Rio Puerco Watershed Management Area, north-central New Mexico.

cooler, higher elevations. The watershed is on the southeastern edge of the San Juan Basin of the Colorado Plateaus physiographic province. Bedrock geology consists of sandstones, siltstones, shales, and limestones ranging in age from Middle Jurassic to Upper Cretaceous. Intrusive dikes and extrusive basalts of Tertiary and Quaternary age are also scattered through the southern reaches of the watershed (Soulliere et al. 1987). Recent alluvium (middle to late Quaternary) and eolian and talus deposits derived from the sedimentary and igneous rocks form the parent material of many soils in the valleys and stream terraces. Readily weatherable "soft" sedimentary lithology dominating the region is largely responsible for the naturally high sediment loads in the Rio Puerco, Rio Salado, and other perennial streams.

Francis (1986) classified the rangeland in the upper Rio Puerco Watershed into 45 ecological phytoedaphic communities based on landform, vegetation, and soil characteristics. Soil and vegetation assemblages representing San Mateo—snakeweed/galleta (*Gutierrezia sarothrae/Hilaria jamesii*) and Querencia—snakeweed/galleta-sand dropseed (*G. sarothrae/H. jamesii-Sporobolus cryptandrus*) were located on the Rock House Allotment approximately 15 km west of San Ysidro village in north-central New Mexico (fig. 1). These two phytoedaphic communities occur extensively throughout the Rio Puerco Watershed Management Area. Slope gradients are 3% on the San Mateo plots and 5% on the Querencia plots. Approximate acreage within the Rio Puerco Management Area is 8,094 ha for the San Mateo soil and 18,211 ha for the Querencia soil (USDA Soil Conservation Service 1990).

Field Methodology and Measurements

Seven bordered runoff collection plots were established to collect runoff and sediment from the two sites. Scholl and Aldon (1988) reported runoff and sediment yields at these sites from 1982 to 1987 and established control calibration periods required to test watershed treatments on the plots. Four plots located next to one another are on the Querencia—Gusa/Hija-Spcr community (Site 1) and three plots are on the San Mateo—Gusa/Hija community (Site 2). These two sites are located only 200 to 300 m from one another and, thus, receive essentially the same precipitation. Total plant cover at Site 1 is generally less than 15%, with 50% of this being broom snakeweed associated with galleta and sand dropseed. Total plant cover at Site 2 is approximately 10%, with 50% broom snakeweed and a larger component of galleta and less sand dropseed than at Site 1.

The rectangular bordered plots at Site 1 are 3.9 m across slope by 9.4 m along slope and have 2,000-liter galvanized steel runoff collection tanks at their lower boundary. Smaller bordered plots (2.4 m × 7.6 m) at Site 2 contain conventional 1,200-liter rectangular stock tanks at their base to collect runoff and sediment. Daily precipitation and runoff were automatically recorded on an A-to-D millivolt recorder and stored onto a magnetic cassette tape. Detailed discussion of installation procedures, construction materials, and automated electrical hardware used in the bordered runoff plots, runoff/sediment collection tanks, and precipitation recording units is in Scholl and Aldon (1988).

A small pit was excavated adjacent to the bordered plots at each of the two sites and the soils were characterized to a depth of 170 cm. Soils were sampled by genetic horizon, and complete profile descriptions including standard morphological features such as horizon thickness, structure, and secondary $CaCO_3$ distribution were recorded following procedures outlined in the USDA Soil Survey Manual (Soil Survey Staff 1981).

Soil texture was determined by the hydrometer method described by Gee and Bauder (1986). Soil organic carbon content was determined by chromic acid oxidation using the modified Walkley-Black method described by Nelson and Sommers (1982). Calcium carbonate equivalent ($CaCO_3$-equiv.) was determined by the acid neutralization method (U.S. Salinity Laboratory Staff 1969).

Infiltration rates for the two soils were determined by rainfall simulation on 1-m^2 plots located immediately next to the established runoff plots. The rainfall simulator, a modified Purdue simulator (Bertrand and Parr 1961) mounted on a 5.25-m-long trailer, delivered an average simulated rainfall intensity of 8 to 9 cm hr^{-1} on two pairs of plots at each study site. Both a dry and wet run were conducted to measure the soils' infiltration rate under dry and wet antecedent soil moisture conditions. Detailed description of equipment and procedures used for the rainfall simulation tests and assessments of soil infiltration rates are in Ward (1986).

Quantity of runoff (cm) associated with each storm was calculated from the measured depth of water in the storage tanks at the base of each plot. As previously mentioned, automated water-level sensors were used to measure the amount of accumulated runoff water and precipitation from each storm event (Scholl and Aldon 1988). Additionally, standard rainfall gauges (collection buckets) were placed at the sites to check precipitation inputs against daily automated recorded data. Manual measurements of water depth in the runoff storage tanks were made weekly to measure the runoff from each plot during the months subject to convective thunderstorms (May–November).

Suspended sediment was measured by extracting a 1.0-liter representative sample from the collection tanks after manually stirring the runoff water and sediment. Sediment concentrations in the suspensions were then determined by drying the samples and weighing the dry sediment. Based on plot and storage tank dimensions, sediment yield rates (kg ha^{-1}) associated with individual storm events were calculated. Average quantities of sediment (kg ha^{-1}) generated by each storm at the two sites were calculated from the replicate plot sediment yields. Differences in average runoff and sediment yield between the San Mateo and Querencia plots were analyzed using t-tests at the 5% probability level.

Table 1.—Physical and chemical properties of the Querencia and San Mateo soils characterized at the two runoff plot sites, Rio Puerco Watershed Management Area.

Horizon	Depth (cm)	Sand	Silt	Clay	Textural class	Structure	Bulk density (Mg m^{-3})	$CaCO_3$-equiv.	Organic carbon
		-------- % --------						------ % ------	
SITE 1 – QUERENCIA SOIL									
A	0–12	74	16	10	Sandy Loam	Loose–F. Gran.	1.38	1.50	0.36
BA	12–25	55	21	24	Sandy Clay Loam	Wk. SBK	1.43	1.38	0.62
Bw	25–48	46	22	32	Sandy Clay Loam	Wk. SBK	1.39	7.18	0.67
Bk1	48–84	45	24	31	Sandy Clay Loam	Mod. SBK	1.46	11.33	0.31
Bk2	84–116	47	22	31	Sandy Clay Loam	Wk. Prism/St. SBK	1.55	5.20	0.24
Bk3	116–148	40	26	34	Clay Loam	Wk. Prism/St. SBK	1.54	2.88	0.24
BC	148–160	42	28	30	Sandy Clay Loam	Wk. SBK	1.34	3.58	0.23
BCq	160–170+	44	26	30	Sandy Clay Loam	Mod. SBK	1.46	2.10	0.13
SITE 2 – SAN MATEO SOIL									
A	0–8	60	16	24	Sandy Clay Loam	Loose–F. Gran.	1.37	0.85	0.45
C1	8–28	52	18	30	Sandy Clay Loam	Massive/St. ABK	1.56	1.13	0.57
C2	28–57	48	24	28	Sandy Clay Loam	Massive/St. ABK	1.49	2.18	0.41
C3	57–90	52	22	26	Sandy Clay Loam	Massive/Mod. ABK	1.52	1.73	0.30
C4	90–111	52	24	24	Sandy Clay Loam	Massive/St. ABK	1.41	1.10	0.27
C5	111–144	52	20	28	Sandy Clay Loam	Massive/St. ABK	1.47	2.35	0.34
C6	144–170+	52	22	26	Sandy Clay Loam	Massive/St. ABK	1.47	2.05	0.33

Results and Discussion

Soil Properties

Soil properties associated with the two sites are listed in table 1. The soil at Site 1 is classified as a fine-loamy, mixed, mesic Ustollic Camborthid based on the criteria established by the USDA Soil Conservation Service (Soil Survey Staff 1975). The soil's textural properties consisted of a sandy loam surface horizon, with sandy clay loam and clay loam subsoils. Structural development was well expressed (prismatic and subangular blocky structure (SBK) in the cambic Bw and Bk horizons), and the soil had a distinct zone of secondary calcium carbonate accumulation (Bk1, Bk2, and Bk3 horizons) showing strong pedogenic development. In contrast, the soil at Site 2 had greater clay content (sandy clay loam texture) in the A horizon. As indicated by massive structure in all but the surface horizon, the soil had only weak pedogenic development. The soil is classified as a fine-loamy, mixed (calcareous), mesic Ustic Torrifluvent.

Table 2.—Infiltration and permeability rates of the soils at the two runoff plot sites, Rio Puerco Watershed Management Area. Infiltration rates were determined by rainfall simulation. Permeability class is based on criteria outlined in USDA Agric. Handb. 18, Soil Survey Manual (Soil Survey Staff 1981).

	Infiltration rate	Permeability class*
SAN MATEO SOIL	Dry: 2.7 cm hr^{-1} Wet: 1.6 cm hr^{-1}	<0.5 cm hr^{-1}
QUERENCIA SOIL	Dry: 5.2 cm hr^{-1} Wet: 3.3 cm hr^{-1}	0.5–12.7 cm hr^{-1}

**Based on structure, texture, and porosity of the most limiting horizon in profile.*

Scholl and Aldon (1988) concluded that Site 2 had been severely eroded and that the soil had lost most of its original topsoil, leaving fine-textured, weathered shale alluvium on the surface. Surface texture and infiltration characteristics of the two soils are different (table 2) and, thus, a significantly higher rate of runoff is likely on the San Mateo soil. Additionally, gravitational water movement through the soil following precipitation would be enhanced in the Querencia plots because of the soil's subsurface structural development which allows a higher permeability rate.

Low organic C content in both soils reflects both low productivity and substantial loss of organic matter via erosion and mineralization (table 1). We attribute the lower organic C content in the surface horizon of both soils to the dominance of wind-reworked soil having a substantially reduced organic matter content. Reduced surface horizon organic matter content results in lower aggregate stability and, thus, enhanced susceptibility to erosion.

Runoff and Sediment Removal

Precipitation within the Rio Puerco Watershed in 1988 was well above average, particularly during the months of June and August. Annual precipitation recorded at the National Oceanic and Atmospheric Administration's monitoring station in Cuba, NM, located approximately 50 km from the plots was 383 mm, 17% above average. During the months of June and August, precipitation recorded at the Cuba station was 180% and 213% above normal, respectively. During 1989, total annual precipitation at the Cuba station was 156 mm, 51% below normal. Monthly totals were lower than average in all months except October, when 56% more precipitation than normal occurred.

Storms generating runoff in 1988 occurred from June 28–29 (2.17 cm) to September 22 (0.89 cm) and from July

Table 3.—Storm precipitation and quantity of runoff and sediment produced on San Mateo and Querencia soils, Rio Puerco Watershed Management Area.

Date	Site & plot	Storm precip. (cm)	Runoff	Sediment yield (kg ha^{-2})
1988				
Jun 28–29*	San Mateo #1	2.17 (1.40 + 0.77)	0.41	162.9
	San Mateo #2	"	0.36	132.6
	San Mateo #3	"	0.34	174.0
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.00	0.0
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Jul 19	San Mateo #1	2.87	0.81	315.4
	San Mateo #2	"	0.89	414.2
	San Mateo #3	"	0.77	362.7
	Querencia #1	"	0.55	86.2
	Querencia #2	"	0.04	7.4
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Jul 30	San Mateo #1	1.28	0.21	55.9
	San Mateo #2	"	0.23	81.6
	San Mateo #3	"	0.21	130.7
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.10	7.5
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Aug 27–28*	San Mateo #1	2.26 (1.76 + 0.50)	0.38	42.7
	San Mateo #2	"	0.37	65.3
	San Mateo #3	"	0.28	49.9
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.04	3.7
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Sept 1	San Mateo #1	1.16	0.55	101.7
	San Mateo #2	"	0.44	99.8
	San Mateo #3	"	0.46	109.7
	Querencia #1	"	0.48	64.4
	Querencia #2	"	0.29	23.1
	Querencia #3	"	0.26	37.8
	Querencia #4	"	0.00	0.0
Sept 11–12*	San Mateo #1	3.02 (1.87 + 1.15)	0.44	36.9
	San Mateo #2	"	0.29	36.6
	San Mateo #3	"	0.44	37.4
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.00	0.0
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Sept 22	San Mateo #1	0.89	0.27	75.2
	San Mateo #2	"	0.17	68.3
	San Mateo #3	"	0.23	101.7
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.10	11.6
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
1989				
Jul 25, 26, 28, 29*	San Mateo #1	6.66 (2.65 + 1.72 + 1.17 + 1.12)	1.86	716.3
	San Mateo #2	"	1.95	621.2
	San Mateo #3	"	2.15	492.1
	Querencia #1	"	0.36	63.8
	Querencia #2	"	0.30	86.1
	Querencia #3	"	0.42	63.0
	Querencia #4	"	0.30	61.2
Aug 1	San Mateo #1	0.39	0.22	46.0
	San Mateo #2	"	0.24	44.2
	San Mateo #3	"	0.20	37.3
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.00	0.0
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0
Oct 3, 4, 5*	San Mateo #1	2.96 (0.39 + 1.44 + 1.13)	0.20	20.3
	San Mateo #2	"	0.18	15.3
	San Mateo #3	"	0.00	0.0
	Querencia #1	"	0.00	0.0
	Querencia #2	"	0.00	0.0
	Querencia #3	"	0.00	0.0
	Querencia #4	"	0.00	0.0

Runoff and sediment accumulations represent totals occurring over these dates. Storms occurred on consecutive dates during interval between runoff and sediment measurements (individual storm contribution to total precipitation responsible for runoff and sediment is indicated in parenthesis).

25–29 (6.66 cm total over a 5-day period) to October 3–5 (2.96 cm total over a 3-day period) during 1989 (table 3, fig. 2).

Quantities of runoff (cm) generated by the storms at the two study sites are contrasted in figure 3. The differences in runoff observed between the two sites were significant for each storm during the 2-year study. A much greater quantity of runoff was generated on Site 2 (San Mateo—Gusa/Hija). Little or no runoff was generated from the Querencia plots during most of the storms. Also, there were distinct differences in quantities of runoff generated by the various storms as compared to the storm's total precipitation. Factors accounting for these observed differences likely included differences in storm intensity as well as differences in antecedent soil moisture contents. Yet, the data also showed a disproportionately greater increase in runoff with increasing precipitation on the San Mateo soil.

Quantities of sediment generated by runoff-producing storms were significantly higher in the San Mateo plots (table 3, fig. 4). Sediment removal averaged 11.9 to 609.9 kg ha^{-1} from the San Mateo plots and 0 to 68.5 kg ha^{-1} from the Querencia plots. The apparent relationship observed when comparing figures 3 and 4 is that, for a given amount of runoff (cm) generated at the two sites, a proportionally greater amount of sediment is generated from the San Mateo plots. This relationship reflects the greater erosive potential of the San Mateo soil.

Total annual runoff and sediment (all storms combined) generated at the two sites are shown in figures 5 and 6. Approximately 21–23% of the total precipitation associated with the storms was lost as runoff on the San Mateo soil, while only 3% of the storm precipitation was removed by runoff on the Querencia soil (fig. 5). Total runoff from the San Mateo plots (2.9 cm in 1988 and 2.3 cm in 1989) was approximately 6 to 8 times greater than the total from the Querencia plots (0.5 cm in 1988 and 0.3 cm in 1989). Total sediment yield (fig. 6) was approximately 10 to 15 times greater from the San Mateo soil (885 kg ha^{-1} yr^{-1} in 1988 and 664 kg ha^{-1} yr^{-1} in 1989) as compared to sediment production from the Querencia soil (60 kg ha^{-1} yr^{-1} in 1988 and 69 kg ha^{-1} yr^{-1} in 1989).

Conclusions

Differences in runoff and sediment rates observed at the two study sites are attributed primarily to the surface textural differences that, in turn, control the rate of water infiltration. Additionally, distinct differences in soil structure that influence permeability may regulate antecedent soil water content, which in turn, influences infiltration and runoff during high intensity storms. Although the San Mateo and Querencia soils have similar subsoil textural characteristics (both soils have particle-size classes defined as fine-loamy), the San Mateo soil with a sandy clay loam surface (24% clay) is subject to slower infiltration and, thus, greater runoff. Furthermore, stronger pedogenic development and well-defined structure in the Querencia soil may more readily allow for gravitational water movement within the profile following saturation, and this in turn may reduce the quantity of runoff water.

Although the San Mateo soil is only half as extensive as the Querencia soil within the Rio Puerco Watershed

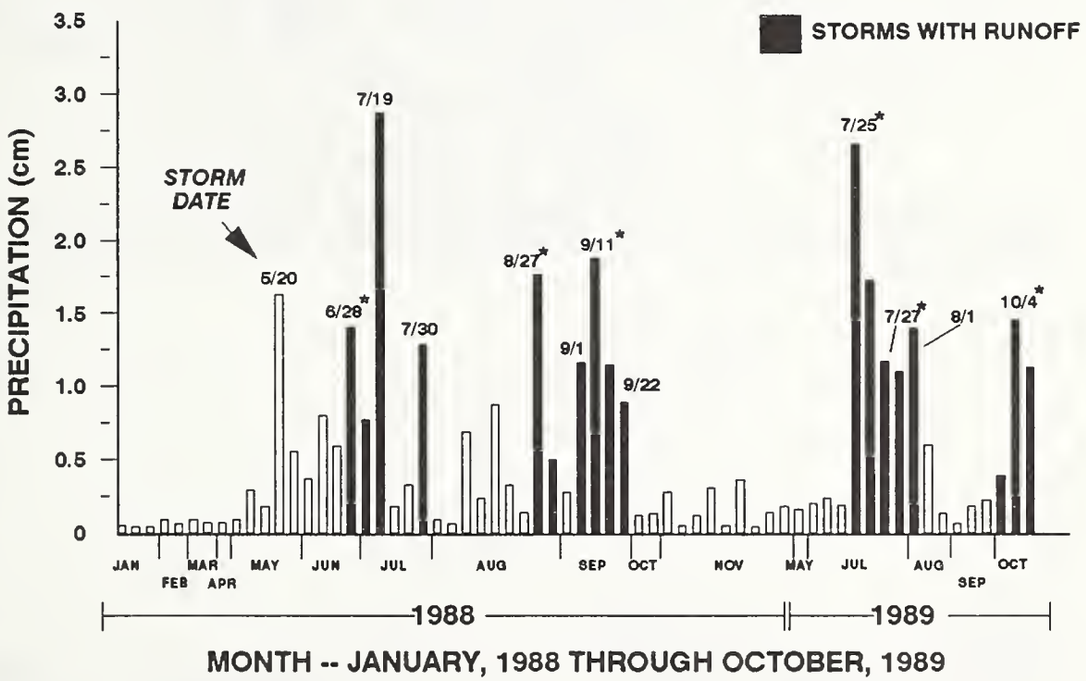

Figure 2.—Distribution of 1988 and 1989 storm events with >0.05 cm precipitation. Dates with an asterisk * denote successive storms that occurred between runoff collection tank measurements; assessments of runoff and sediment for individual storms during these periods were not possible.

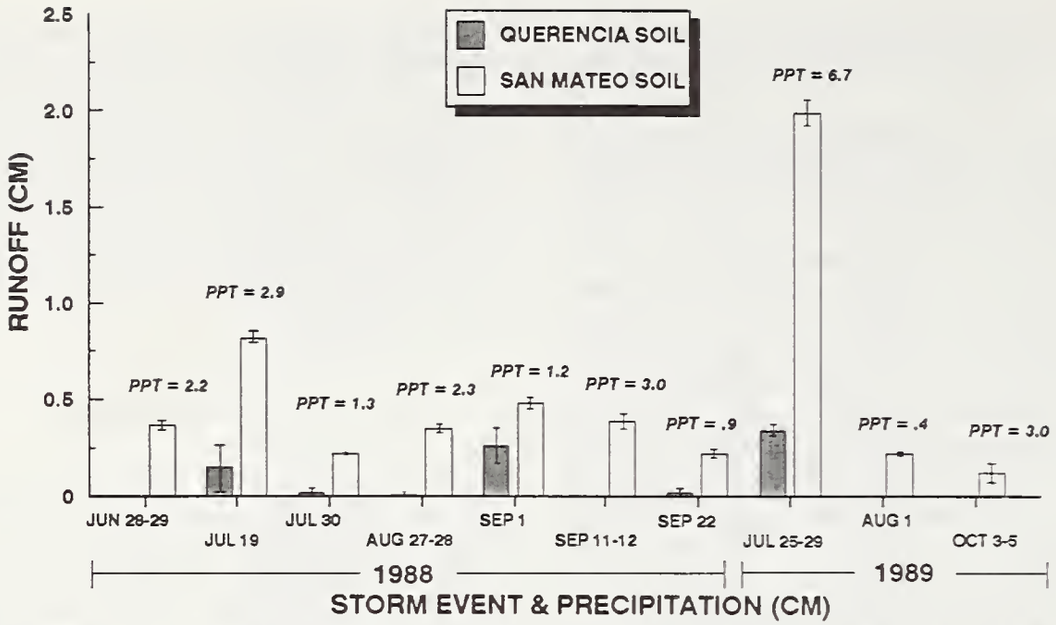

Figure 3.—Runoff generated from the two soils by 1988 and 1989 storms. Values are means for the replicate plots at each site (standard deviations about means are indicated by vertical bars).

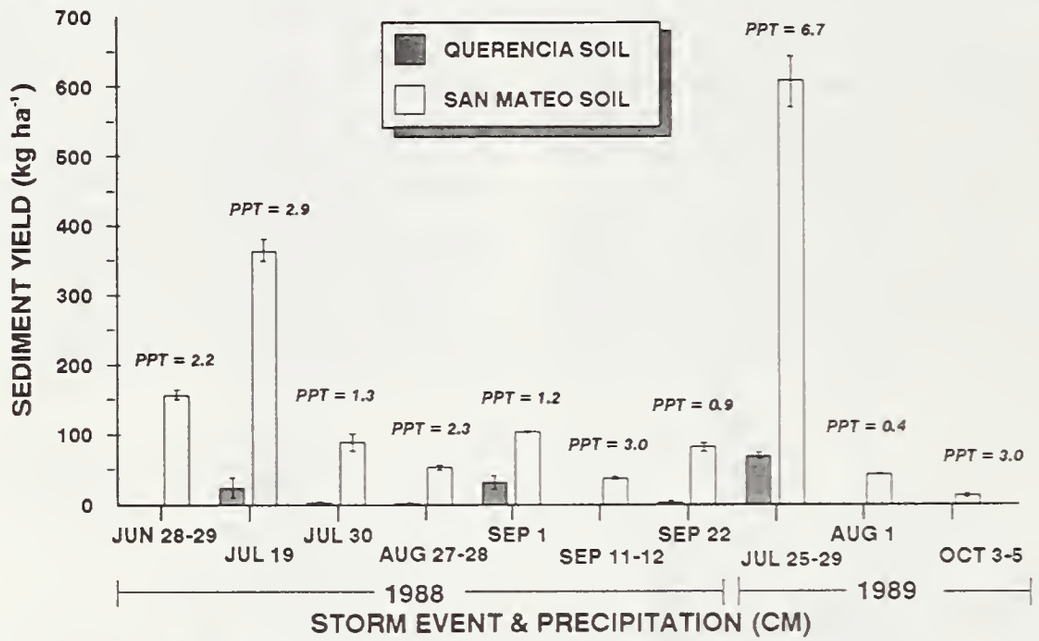

Figure 4.—Sediment removed from the two sites by storm runoff in 1988 and 1989. Values are means for the replicate plots at each site (standard deviations about means are indicated by vertical bars).

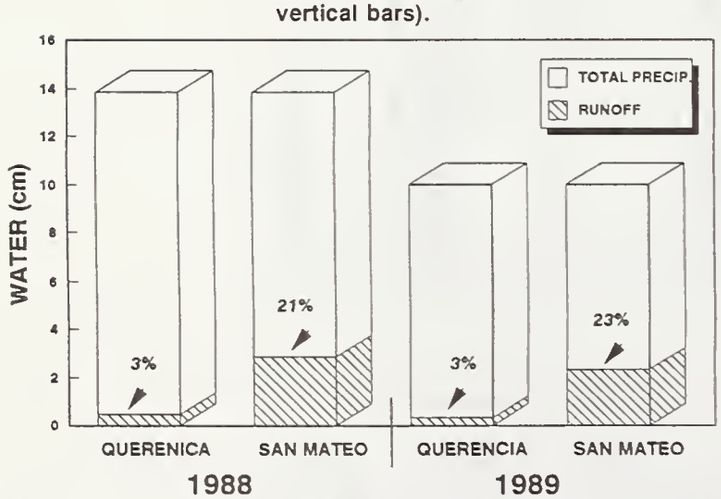

Figure 5.—Proportion of total annual precipitation removed by runoff from the two study sites in 1988 and 1989.

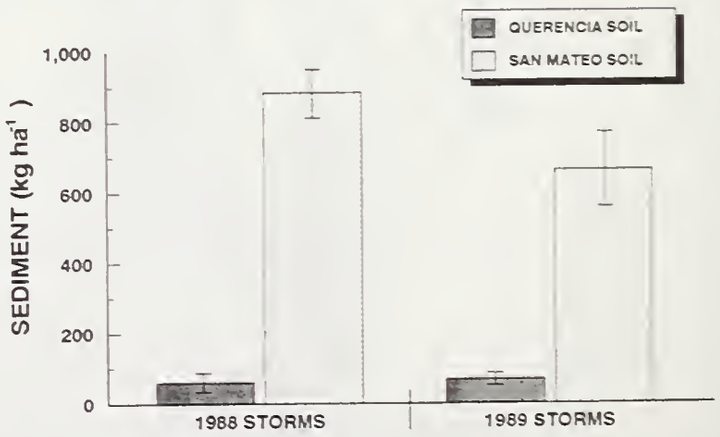

Figure 6.—Total sediment (all storms combined) removed from the two study sites in 1988 and 1989 (standard deviations about means are indicated by vertical bars).

area, this soil generated 6 to 8 times more runoff and had a sediment yield rate that was 10 to 15 times greater. These study results suggest that management practices aimed at reducing erosion and sediment within the Rio Puerco Watershed Management Area might be better directed toward those soils that contribute most to the problem. Higher return in benefits can be expected if resources are expended in attempting to restore those soil/vegetation assemblages with the highest runoff and erosion rates.

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Rocky Mountains

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Rocky Mountain Forest and Range Experiment Station

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